# Researchers discover new chiral property of silicon, with photonic applications

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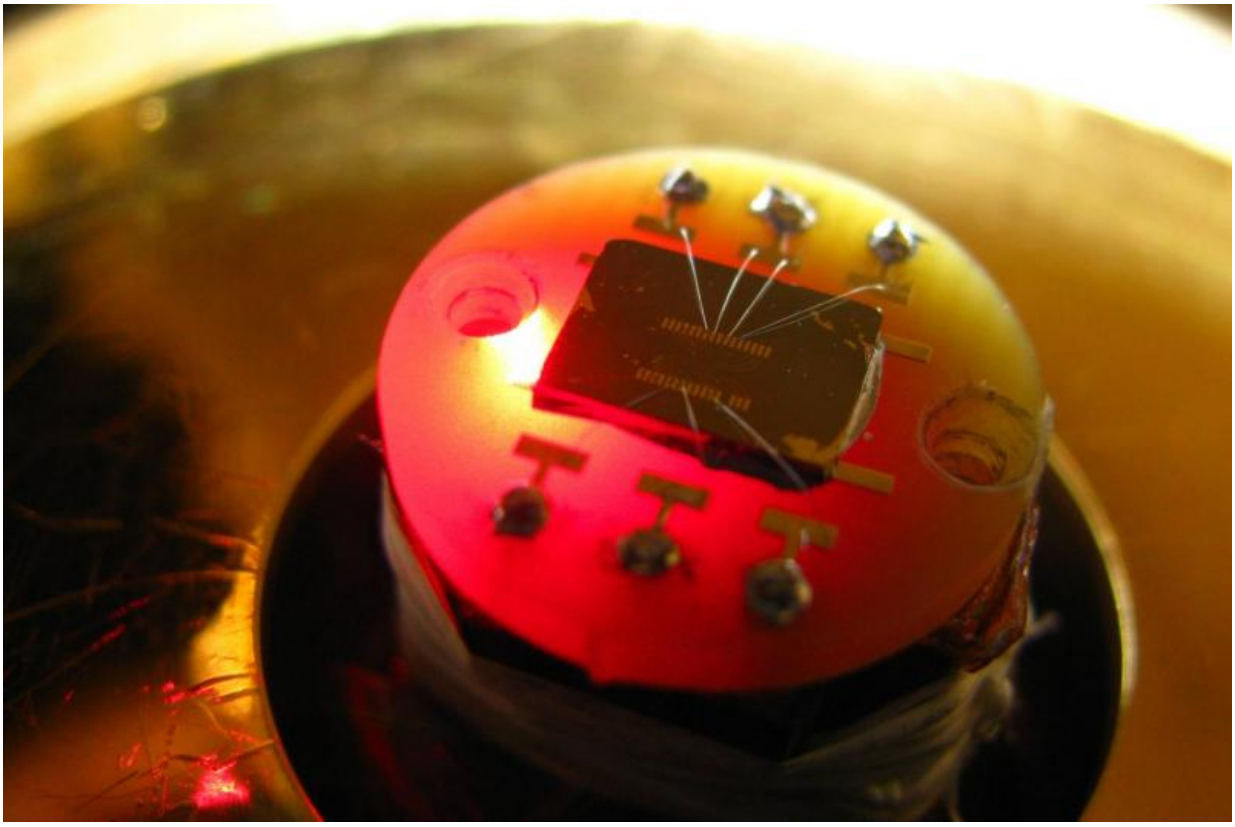

By encoding information in photons via their spin, photonic computers could be orders of magnitude faster and efficient than their current-day counterparts. Likewise, encoding information in the spin of electrons, rather than just their quantity, could make spintronic computers with similar advantages. University of Pennsylvania engineers and physicists have now discovered a property of silicon that combines aspects of all of these desirable qualities. In their experimental set-up, pictured here, they a silicon-based photonic device that is sensitive to the spin of the photons in a laser shined on one of its electrodes. Light that is

polarized clockwise causes current to flow in one direction, while counter-clockwise polarized light makes it flow in the other direction. Credit: University of Pennsylvania

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University of Pennsylvania engineers and physicists have now discovered a property of silicon that combines aspects of all of these desirable qualities.

In a study published in *Science*, they have demonstrated a silicon-based photonic device that is sensitive to the spin of the photons in a laser shined on one of its electrodes. Light that is polarized clockwise causes current to flow in one direction, while counter-clockwise polarized light makes it flow in the other direction.

This property was hiding in plain sight; it is a function of the geometric relationship between the pattern of atoms on the surface of silicon nanowires and how electrodes placed on those wires intersect them. The interaction between the semiconducting silicon and the metallic electrodes produces an electric field at an angle that breaks the mirror symmetry that silicon typically exhibits. This chiral property is what sends electrons in one direction or the other down the nanowire depending on the polarity of the light that hits the electrodes.

The study was led by Ritesh Agarwal, a professor in the Department of Materials Science and Engineering in Penn's School of Engineering and

Applied Science, and Sajal Dhara, a postdoctoral researcher in Agarwal's lab. They collaborated with Eugene Mele, a professor in the Department of Physics and Astronomy in Penn's School of Arts & Sciences.

"Whenever you change a symmetry, you can do new things," said Agarwal. "In this case, we have demonstrated how to make a photodetector sensitive to a photon's spin. All photonic computers need photodetectors, but they currently only use the quantity of photons to encode information. This sensitivity to photon spin would be an extra degree of freedom, meaning you could encode additional information on each photon.

"Typically, materials with heavy elements show this property due to their spins strongly interacting with electron's orbital motion, but we have demonstrated this effect on the surface of silicon, originating only from the electron's orbital motion"

Agarwal and Dhara reached out to Mele due to his work on topological insulators. He, along with fellow Penn physicist Charles Kane, laid the foundation for this new a class of materials, which are electrical insulators on their interiors but conduct electricity on their surfaces.

Agarwal's group was working on various materials that exhibit topological effects, but as a check on their methods, Mele suggested trying their experiments with silicon as well. As a light, highly symmetric material, silicon was not thought to be able to exhibit these properties.

"We expected the control experiment to give a null result, instead we discovered something new about nanomaterials," Mele said.

Silicon is the heart of computer industry, so finding ways of producing these types of effects in that element is preferable to learning how to

work with the heavier, rarer elements that naturally exhibit them.

Once it was clear that silicon was capable of having chiral properties, the researchers set out to find out the atomic mechanisms behind it.

"The effect was coming from the surface of the nanowire," Dhara said. "The way most silicon nanowires are grown, the atoms are bound in zigzag chains that go along the surface, not down into the wire."

These zigzag patterns are such that placing a mirror on top of them would produce an image that could be superimposed on the original. This is why silicon is not intrinsically chiral. However, when metal electrodes are placed on the wire in the typical perpendicular fashion, they intersect the direction of the chains at a slight angle.

"When you have any metal and any semiconductor in contact, you'll get an electric field at the interface, and it's this field that is breaking the mirror symmetry in the silicon chains," Dhara said.

Because the direction of the electric field does not exactly match the direction of the zigzag chains, there are angles where the silicon is asymmetric. This means it can exhibit chiral properties. Shining a circularly polarized laser at the point on the nanowire where metal and semiconductor meet produces a current, and the spin of the photons in that laser determines the direction of the current's flow.

Dhara and Agarwal are currently working on ways to get planar silicon to exhibit these properties using the same mechanism.

**More information:** *Science*, www.sciencemag.org/lookup/doi/ … 1126/science.aac6275

Provided by University of Pennsylvania

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